THE ORIGIN OF FAST ELECTRONS PRECIPITATION IN THE POLAR ATMOSPHERE

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The Earthward Hall electric field generation in the tail current sheet was demonstrated in IKB-1300 space craft measurements and confirmed in laboratory simulation and numerical solution of MHD equations. The electric field produces field-aligned currents (FAC). The current enhancement take place during a substorm. The electrons acceleration occurs in FAC potential drops. The model explains plasma injection into magnetosphere at the substorm.

1. There are many evidences that fast electrons produced discrete aurora are accelerated in potential drops along the magnetic field lines. The idea of the potential drop appearance is in the good agreement with many experimental and theoretical works [1,2], which have demonstrated appearance of double electrical layers and/or regions of anomalous resistivity, when the electron current velocity in FAC reaches some critical value, usually (T_e/m_i) . Here T_e is the electron temperature, m is the ion mass. The typical for a substorm FAC critical velocity can be reached at altitude of R_E.

The most important problem for understanding of electron acceleration phenomena is comprehension of FAC generation at a substorm. The measurements carried out on IKB-1300 spacecraft [3] in the polar region near midnight permitted to make conclusions about the current generator location. The instruments observed two main FAC layers directed oppositely to each other. The FAC layers intersect the ionosphere along the polar oval. The downward current is situated at the higher latitude. The thickness of the FAC layer is of ~100km, the current density is of 2-4 mA/cm^2.

The measured electric field was located between two oppositely directed FAC layers and was perpendicular to them. The direction of Pedersen current, which connects FAC layers, was the same as the E direction. The westward jet was observed by ground based magnetometers at FAC increasing.

The electrojet value and direction correspondent to Hall current. These measurements show, that energy dissipation Ej>0 occurs in the ionosphere.

2. The FAC supply the energy from a distant part of the magnetosphere. The FAC projection along magnetic field lines shows, that the current generator is located in the magnetosphere tail at distances of 10-20 R_E.

The mechanism of Earthward electric field generation in the magnetotail current sheet can be understood, if the current is transferred by electrons. The strong electric field generation should occur at current density increasing in the tail current sheet (CS) during a substorm.

According to the measurements [4] the main feature of the plasmadynamics in the tail during a substorm development is sharp decreasing of the current thickness up to 0.1R , while the total current almost not changes.

The simple analysis of equations for electrons and ions:

$$m_e d\mathbf{V}_e/dt = -\nabla p/n - e(\mathbf{E}+\mathbf{V}x\mathbf{B}/c) + e\mathbf{J}/\sigma$$
$$m\ dV\ /dt = -\nabla p/n + e(\mathbf{E}+\mathbf{V}x\mathbf{B}/c) - e\mathbf{J}/\sigma$$

demonstrates the electric Earthward field generation in the tail current sheet. Considering projection of equations on Sun-Earth axis (Solar - terrestrial coordinates) one can neglect the j_x/σ term. It is well known that the tail CS can not be considered as a static equilibrium system. The plasma flow plays an important role in current sheet dynamics. The strong Earthward plasma flow was observed during development of the geomagnetic activity [5]. This fact demonstrate that **JxB**/c is much bigger then ∇p. Another important result was obtained at ion flux measurements in the CS [5].

The work demonstrated absent of any West-East asymmetry of ion velocity (V~(3-5)x10^7 cm/s). The result proved suggestion that the current in CS is carried by electrons. This is very typical for CS in the laboratory and space plasma.

It should be emphasized that the presence of a magnetic field normal component contradicts to CS consideration, as a system without a plasma flow. In such a model the ion pressure gradient is balanced by magnetic lines tension, and the current density is expressed by the well known formula for the diamagnetic current $\mathbf{J}=c\mathbf{B}x\nabla p/B^2$.

Let as consider homogeneous CS : $j=j_y$ and $B=B_x$ do not depend on X. In equilibrium the plasma pressure in direction perpendicular to CS is balanced by the force J_yB_x/c. For a CS $\partial B/\partial z$ does not depend on X. That conditions are corresponded to well known Haris CS model - neutral CS. To make the model more realistic one it is necessary to apply the magnetic field B_z perpendicular to CS. In that case for the equilibrium it is necessary to balance B_zj_y/c by $\partial p/\partial x$. Now p must depend on X. This contradicts to CS homogeneity along X axis.

So the equilibrium without plasma flow is impossible, and current in the tail CS at $p_i>p_e$ can not be explained by the ion diamagnetic current.

The difficulty of the static force balance arises also in the frame of single particle approximation. Particle confinement in the CS is possible only for particles with big pith angles.

Such unstable conditions can not exist for a long time. All these assumptions bring as to the Earthward electric field in the CS:

$$\mathbf{E} = \mathbf{J}x\mathbf{B}/(nec)$$

This electric field can produce FAC and accelerate ions to the Earth in presence of a weak magnetic field normal component. For n =0.3 cm^{-3}, B =0.3 γ, B =20 γ, tail thickness at substorm [4] δ = $0.1R_E$, we have E= 2 mV/m. The projection of E along equipotential magnetic lines is in good agreement with electric field. measurements in the polar region.

3. The Earthward electric field creation in the magnetotail was demonstrated in laboratory simulation experiments [6]. For a correct reproduction of the space phenomena in the laboratory the principle of limited simulation was used [7]. The experiments were carried out in the artificial magnetosphere, which was created at supersonic and superalfvenic plasma flux (artificial Solar wind) interaction with the magnetic dipole. This result proved the theory of the Earthward electric field creation and ions acceleration in this field.

The most important feature of a substorm is sharp decreasing of the tail CS thickness. The sharp CS thickness decreasing can be explained by plasma losses because of plasma pushing out of CS by **jxB**/c force. The plasma losses can not be compensated any more by plasma inflow from the current sheet boundaries [8]. The CS thickness decreasing is following by j increasing, because the tail magnetic field B is almost unchanged. The **JxB** force increases, e.g. process looks like a flare. If such a flare (substorm) really occurs after supplementary energy input into magnetic tail, the numerical simulation of sharp CS thickness decreasing should be made by the following way. The CS should be created by plasma flux interaction with the magnetic field. When the stationary CS is created, the external plasma flux should be ceased. No energy will be supplied into the CS after switching the flux off.

4. In our numerical simulation the D mode of PERESVET program was used [9]. The MHD equations (see [9]) were solved in 61x61 grid. The superalfvenic plasma jet was injected in transverse magnetic field in low density plasma ($\beta<<1$). The jet dynamic pressure nmV^2 was bigger then $B^2/8\pi$. The dimensionless parameters (magnetic Reynolds number, ratio of plasma pressure to magnetic one, Alfvenic Mach number) were choose according to the principal of limited simulation: $Re_m=10$, $\beta=10$, $M_A=4$.

The jet was injected perpendicular to the magnetic field of two dimensional dipole (Fig.1). No MHD instability was observed at CS formation and in stationary state during plasma jet injection. Apparently, the fast plasma stream transported all occasional disturbances from the region and does not permit to develop any MHD instability. The stationary state was established at $t\sim3L/V_o$. The field of velocity vectors and magnetic field lines for t=0.9 Alfven times are shown in Fig. 1 at upper panels. Supper Alfvenic plasma jet was injected from the left boundary. At t=0.9 the plasma injection was ceased and **jxB** force began to push plasma back from the sheet. The sharp decrease of the CS thickness takes place, and in the region of V~0, where plasma flux reverses its direction, MHD instability is developed. The typical for tearing mode ring is observed at t=1.531 (lower panels).

This instability increases energy dissipation typical for a substorm.

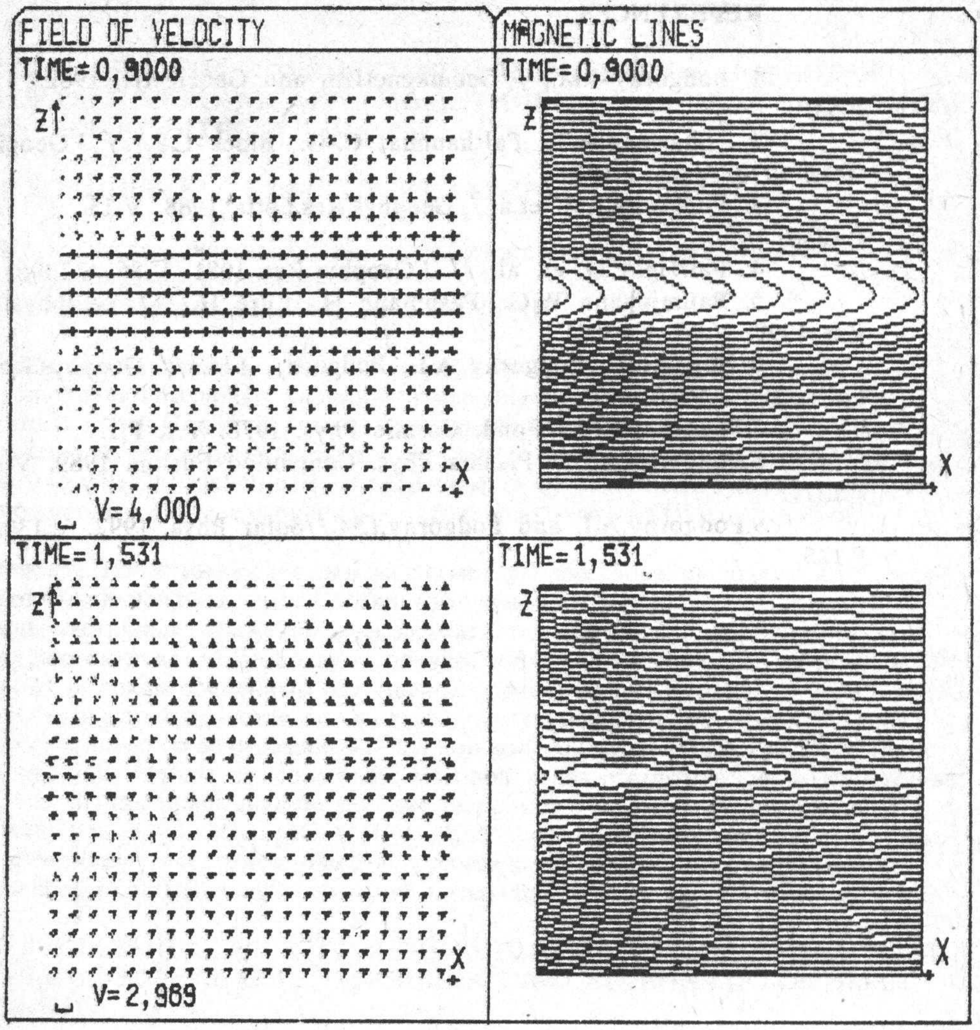

Fig.1. The field of velocity and magnetic lines during the stationary phase at plasma injection (upper panels) and at fast magnetic field dissipation (lower panels) after injection switching off.

5. **Conclusion.** The set of data from satellites and ground based measurements, laboratory simulations and numerical solutions of MHD equations demonstrate possibility to produce the tail electric field **E** = **jxB**/nec. The electric field enhancement occurs during the substorm.

This electric field can generate FAC, and electron acceleration take place in the field-aligned electric field. These fast electrons accelerated in upward current precipitate in upper atmosphere and produce aurora enhancement at the substorm.

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